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Freshwater Flow Diversion and its Implications for Coastal Zone Ecosystems

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County Sanitation Districts
Orange County, California

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Introduction

The current attitude toward utilization of river runoff is based on the erroneous assumption that supply would never be a limiting factor on agricultural and urban growth or have any serious impact on riverine/marine environment. However, this approach has had devastating effects on semi-arid and arid ecosystems in the south of Ukraine and Moldova, Central Asia, eastern Mediterranean and western Africa, and some western states of the United States. The cause is that the natural renewability of runoff is limited by geophysical and meteorological properties of each watershed. Not recognizing this natural phenomenon has led to overestimation of water surplus. This, in turn, has triggered overpopulation and despoliation of the water ecosystems whose limit of tolerance is prescribed by nature's universal laws.

Societal Effects of Watershed Development

The experience gained from studying the extensive watershed development in the former Soviet Union is instructive for western society (Rozengurt 1991).

Unarguably, a similar development has been looming over the horizon in the U.S., where enormous water projects undertaken in the 1930s to 1960s had been focused on purely political or economic local, state or federal goals toward multi-utilization of water and land resources (California and Texas semi-arid zones). Subsequently, the preservation and balanced optimization of watershed environments were not given equal weight in water management planning processes; the ecological appraisal of natural runoff limitations were not discussed. Therefore, environmental goals and societal goals and objectives related to them were all but neglected and known ecological tolerances of riverine/estuarine systems to water diversions were ignored. Three decades later this failure hampered the Columbia, Sacramento, San Joaquin, and Colorado and Gulf of Mexico river ecosystems, as it did the Nile River's normal functioning (Duke and Sullivan 1990, Halim 1991, Leet et al. 1992, Rozengurt and Haydock 1991, Sherwood et al. 1990).

Habitat loss due to human manipulation of the natural hydrological cycles of rivers has evolved new, unprecedented ecological crises and precipitous declines of commercial and recreational fisheries and shellfish. The general sequence of deleterious events in coastal zones of Central and South Atlantic and Western Pacific are the same as those in the Black, Azov, Caspian, Aral and eastern Mediterranean seas and other parts of the world oceans. Among many causative factors which triggered these processes, the four *"Ds"*—*dams, diversion, dewatering* and *desertification* of arable land—have played significant roles in the economic downfall and deterioration of semi-arid zones' infrastructures.

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Ecosystem Effects of Perceived Watershed Development

The direct origin of the four "Ds" is related to the following typical erroneous doctrines: (1) the effect of rivers impoundment on deltaic/estuarine/coastal environment can be of limited significance, and some negative development, say, in fishery losses can be mitigated through rearing of fish in hatcheries or providing special paths for migration to spawning grounds; (2) surface (river) and groundwater runoffs are inexhaustible; (3) deltas should be effectively transformed into a plumbing network to serve local and long-distance water conveyance facilities; and (4) river runoffs into coastal ecosystems are wasteful. The following are brief descriptions of some major ecological and economic consequences of implementation of these fallacious doctrines in water management practice.

1. As known, the first doctrine contradicts completely the essence of river ecosystems' functioning, for a river parted by dams is no longer one ecosystem. Strategic essence of the first doctrine has put aside the major societal and environmental objectives, namely, protection, preservation and conservation. Several decades later this neglect has entailed some grim repercussions. The modified runoff seasonal and annual values (volumes and timing of discharges, velocity, temperature, oxygen, nutrient, and sediment load) do not retain significant pre-project essentials to support migration, breeding and maturity of fish or maintain tolerant habitat (Leet et al. 1992; Rozengurt et al. 1987a, 1987b).
2. The assumption of inexhaustible runoff was, is and will be profoundly wrong, for it denies the fundamental stochastic principles of runoff formation, cyclicity and limitation of its renewability within strictly defined watersheds. As a result, human-induced subnormal wetness or even droughts, particularly in spring, for the last three to four decades persistently have prevailed regardless of precipitation over watersheds. Notably, remnants of spring regulated runoff often is less than 30—35 percent of normals and the frequencies and absolute values of the deviations are up to −40 to −85 percent (instead ± 25 to 30 percent for unimpaired runoff (Figure 1). Subsequently, since the 1960s, the frequency of occurrence of years of dry, critical dry or drought-like conditions (particularly in spring) have increased three to five times in comparison with unimpaired runoff over 55—100 years. These perennial water deficits have plagued river flushing and coastal rejuvenation and become chronic events of nearly global proportion; the Nile, San Francisco Bay; Gulf of Mexico river networks, except the Mississippi; Colorado River and Southern California Bight; the Black, Azov, Caspian and Aral seas; etc.

The residual runoffs usually are in disconcert, either singly or simultaneously, with water demands for fish migration and spawning versus power production and irrigation in the most vital period of the year—spring (Rozengurt et al. 1985, Rozengurt and Hedgpeth 1989). Undoubtedly, this new, acutely negative phenomenon has eliminated alternate historical probabilities and duration of years of different wetness. With time, these non-equilibrium conditions have imposed deleterious changes on the coastal zones due to immense losses of waters' organic and inorganic matter, sediment load, oxygen, etc. Their cumulative totals much exceed anything known for the last millennium.

Suffice to say, for example, that in the last two decades spring inland water use had deprived the Black/Azov Sea basin nearly 1,700 cubic kilometers freshwater (three times the volume of the Sea of Azov) and the Caspian Sea of 1,000—1,200 cubic kilometers (equal to the North Caspian volume). At the same time, the runoff of two major rivers

of Central Asia—Amu Darya and Syr Darya—to the infamous, landlocked Aral Sea ceased to exist (freshwater deficit has reached 1,300—1,400 cubic kilometers). This has triggered catastrophic reduction of surface area, volume (down to 40 percent of that in 1964) and a four-fold increase in salinity. And the sea, a formerly rich basin, teeming with valuable fish (44,000 tons average annual harvest in the 1940s through the 1960s) has turned into a deadly, receding, hypersaline lake (Figure 2).

Modification of watershed has impaired ecological properties of some major rivers in Northern (Nile) and Southern Africa (Zambezi, Myobenselini, Kwa-Zulu), and Near East (Tigris and Euphrates), China (Yellow and Yangtze), and India (Indus); similarly impaired in the U.S. are the Columbia, Sacramento, San Joaquin, Colorado, Appalachicola and numerous other rivers of the Gulf of Mexico; the California Bight, some 26 coastal plain rivers have been dammed and water was diverted from their natural course. As a result, about 95 percent of formerly rich wetlands have completely disappeared, and kelp sustainability in proximity of the mouths of these rivers is very limited and fragile. The "domino effect" of consequences of these modifications are appalling and, unfortunately, irrevocable if ecological integrity and health of the ecosystems are in question.

3. The third doctrine reflects a typical, single-minded authoritative attitude toward managing deltas as plumbing systems. Such an approach demonstrates the lack of knowledge of the dynamic deltaic complex for sustenance of coastal waters as a whole.

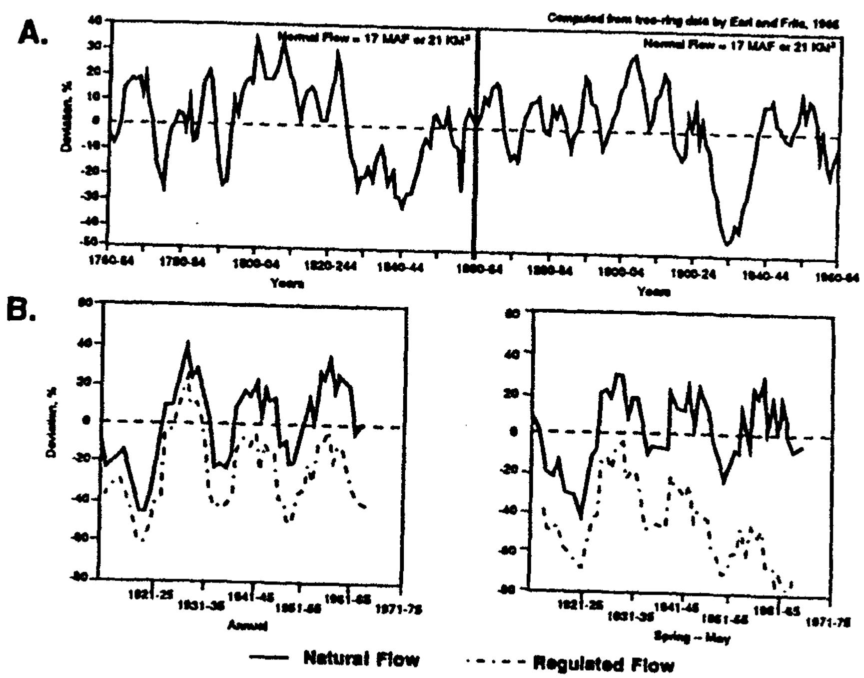


Figure 1. (A) Deviation of the five-year running mean combined four river runoff of normal for 200 years, (B) Deviation of the five-year running mean runoff to normal to the San Francisco Bay.

Historically, the delta is the heart of estuarine/coastal ecosystems and the most suitable home, nursery and breeding ground for many commercially important species. In processes of their evolution, deltas have received organic and inorganic load from upstream and produce, circulate and reprocess nutrient increment (about 70 percent) within their freshwater body, and maintain the unique richness of deltaic bodies. Furthermore, the delta outflow acts as a buffer zone to repel saltwater intrusion, and flushes the natural and human introduced pollutants. Over millennia, this natural process maintains optimal tolerant salinity equilibrium and enforces entrainment, mixing and enrichment of estuarine and coastal waters by introducing million tons of oxygen and other matter vital for survival and reproduction of fish and shellfish.

However, when human-induced subnormal wetness prevails, myriads of negative features are developed nearly simultaneously. Among them, the salinization of estuarine waters is the most insidious, the inverse of the runoff process (Figure 3). Another development is trapping sediments behind the dams. This aggravates subsidence of levees and increases the danger of catastrophic flooding of deltaic croplands and erosion of deltaic tributaries. For example, the High Aswan Dam built on the Nile River in 1964—1965 has deprived its delta and its coastal perimeter of about 140 by 10^6 tons per year of fine sand, silt and clay. As a result, the geomorphologic equilibrium between the delta and coastal zone has all but vanished and the Nile deltaic perimeter (200 kilometers in length) has retreated toward the south with the speed of 125—175 meters per year (Halim 1991). In the Sacramento/San Joaquin Delta sediment losses alone ranged between 70—90 million tons (since 1945). This, coupled with scouring and erosion, has provoked the subsidence of levees and deltaic arable land to the point where maintenance of some of them is considered economically useless.

The diking, channelization, straightening and deepening of deltaic tributaries to accommodate much of spring delta outflow or conversion of marshes, wetlands and deltaic

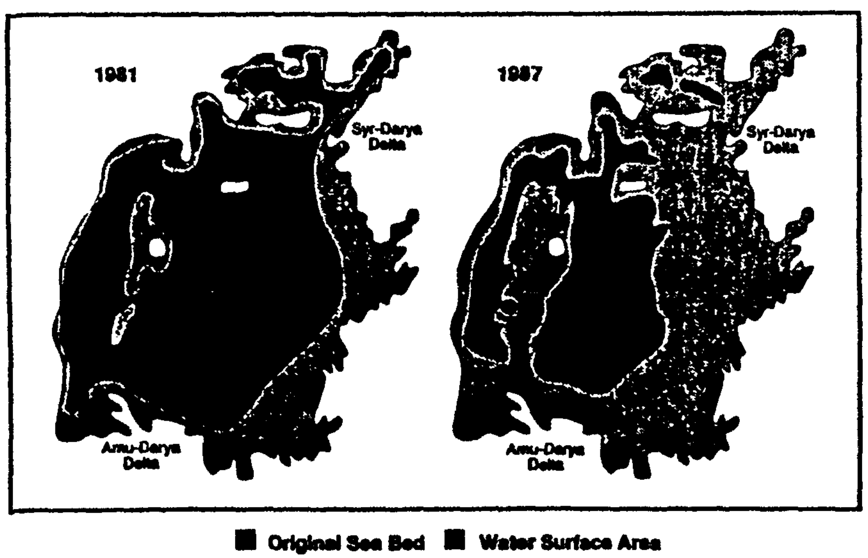


Figure 2. Aral Sea desertification.

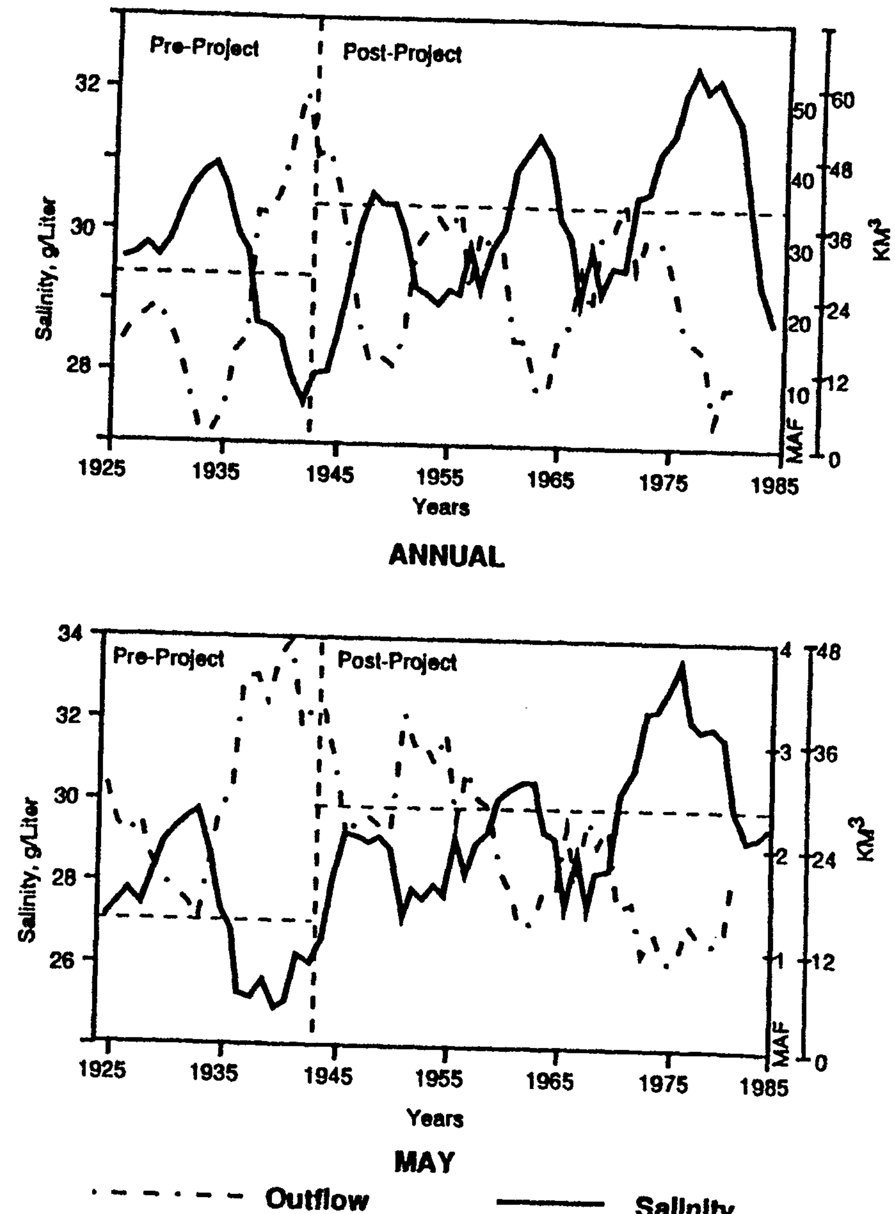


Figure 3. Chronological fluctuations of the five-year running mean delta outflow and salinity of surface water at the Golden Gate, San Francisco Bay.

islands to cropland has led to the denudation, dewatering and desertification of the deltaic islands and banks that further aggravate their environment by increased warming, evaporation, eutrophication and erosion. The dewatering, in concert with salt intrusion, fortifies abnormal density stratification that provokes oxygen deficiency (hypoxia) and mass mortality of vegetation and living creatures. Note that, after 15—25 years of such extremes, many of the discussed deltas have acquired a "ghost" composure in comparison with their lustrous past.

The Sacramento/San Joaquin Delta encapsulates many of the negative developments found in other systems. But, to our dismay, one particular process, namely, the relentless carnage of millions of fry at pumping station screens, makes this delta notoriously unique. Over the last 36 years, cumulative water losses for the Delta alone of up to 100 million acre feet (78 times the delta volume) were accompanied by striped bass and salmon fry kills at pumps' screens (Figure 4) three times higher than that of reported fish kills due to all causes for all 22 coastal states between 1980—1989 (Lowe et al. 1991). Arguably, but according to California Department of Fish and Game, toxicity is not the issue it was in the 1950s—1960s; runoff depletion in the delta has made these and other fishes nearly endangered species.

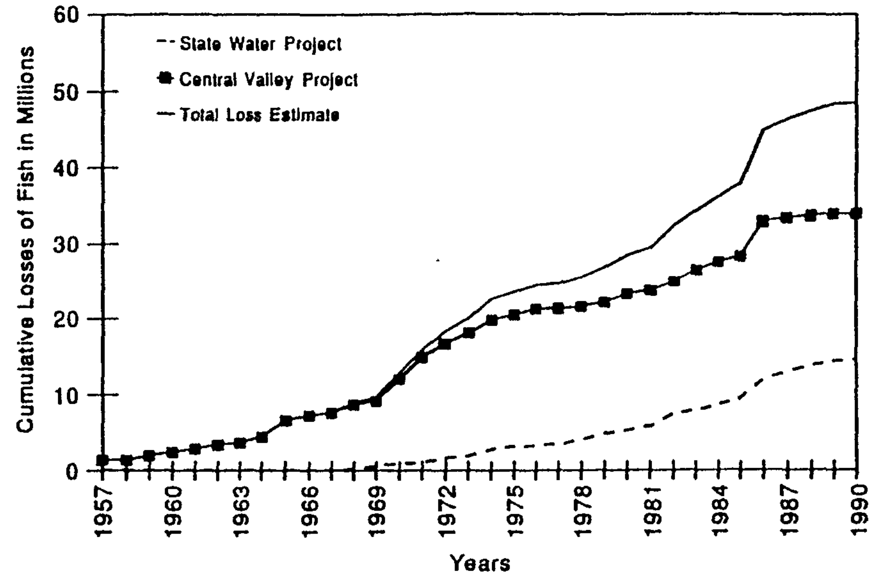
Notably, the same conclusion had been presented by the senior author to the California Department of Fish and Game and the National Oceanic and Atmospheric Administration (NOAA) in a series of letters, publications and reports in 1980—1987. Unfortunately, these programs were ignored. Therefore, the time to stop the despoliation of valuable fishes was lost.

4. The fourth doctrine unscrupulously assaults the causative origin and formation of estuarine and coastal environments for thousands of years. Specifically, the "freshwater runoff is a waste" approach to estuaries denies their definition as a cradle of the highest biological productivity of adjacent coastal areas. Their plumes (coastal hydrofront) through mixing and entraining action enhance manyfold over the rejuvenation of coastal waters. This annual renewal is necessary to sustain a thriving biota, for their life cycle (migration, breeding, feeding) is much adjusted to seasonal runoff fluctuations. Even strictly marine species indirectly, through the food web, profit from the richness of estuarine flow and biota. That is why a five-mile-wide band along the shoreline of the coastal shelf is the major fish provider.

Conclusion

Failure to recognize the above mentioned historical facts and not incorporate them into risk assessment analysis of water project alternatives encourages unrestrained water development. Unchanged, this policy leads to the detriment of both society and the environment. The west coast examples of the annihilation of salmon in the Columbia River and Sacramento/San Joaquin River networks (as well as striped bass and shad in the latter) in our daily news are vivid reminders of incompatibility between the sustainable environment and human's excessively perceived water needs. Even worse conditions typified the southern estuarine/coastal ecosystems of the former U.S.S.R. There, the biological impoverishment has reached the scale of ecological cataclysm unseen or undocumented, as least since Ivan the Terrible. In general, the coastal ecosystems of southern seas have become impaired and formerly rich habitats fragmented.

It must be emphasized that the first signs of pending peril appeared in three seas—Black, Azov and Caspian—nearly simultaneously in the mid-1960s. By that time about



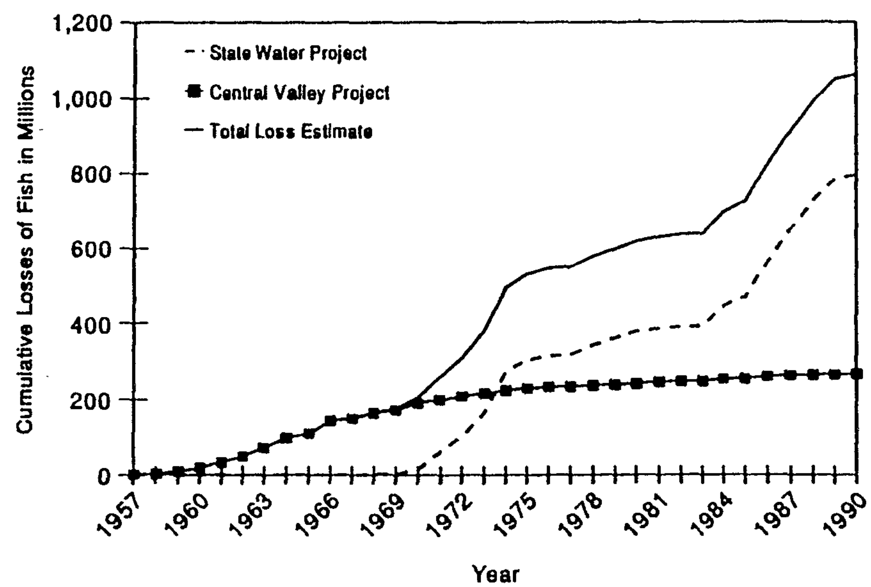


Figure 4. (A) Cumulative losses of the chinook salmon (21–150 mm) at the Sacramento—San Joaquin Deltaic Pumps (1957–1990). (B) Cumulative losses of stripped bass (21–150 mm) at the Sacramento—San Joaquin Deltaic Pumps (1957–1990).

20 large dams became operational. For example, in the Sea of Azov, the pearl of biological productivity among all other southern seas, the catch for most prized anadromous and semi-anadromous fish was nearly nullified by the 1970s. The cumulative economic losses alone mounted to billions of dollars, and hardship shadowed the lives of millions.

The significant cumulative losses of freshwater behind numerous dams of the Danube (28—40 percent of spring normal runoff is diverted annually), Dniester (45—75 percent) and Dnieper (45—85 percent) draining to the Black Sea reduce the intensity of vertical and horizontal mixing (entrainment) and seasonal turnover many times. Subsequently, relatively deep and bottom waters of western Black Sea (maximum depth around 60 meters) have been left for years isolated from sources of oxygen. As a result, more than 10,000—15,000 square kilometers of area have become stagnant and anoxic. This triggered the disintegration of 10 million tons raw weight of the algae *Phyllophora* (sort of a floating kelp) and diversity of benthic organisms and flatfish. Nearly the same has happened in the Sea of Azov, where summer recurrence of anoxia occupies over 10,000—20,000 square kilometers (one-sixth to one-third of sea area) of subsurface and bottom layers; similar events were observed in the Gulf of Mexico (Duke and Sullivan 1990). It appears that increased recurrence of human-induced years of droughts substantially exceeds the tolerance limit of coastal embayments for recuperation, and remnants of runoff have effectively lost the ability to restore biological equilibrium to the coastal zones. The interrelation between eastern Mediterranean fishery and the Nile river regulated runoff before and after the Aswan Dam became operational provides strong support to this statement (Halim 1991) (Figure 5).

Overall the evidence is clear that only 25—30 percent of historical runoff is available for other uses, without radically affecting ecological balance in natural watersheds the world over. From the coastal shelf humankind can reap only what is sowed by the productive waters of the land.

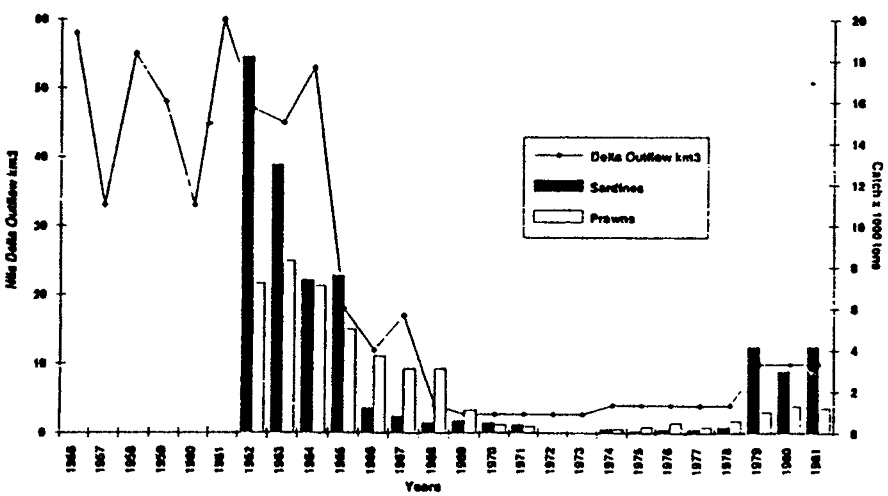


Figure 5. Relationship between Nile Delta annual regulated outflow and Mediterranean Sea coastal catch of Egypt.

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